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Acid Aerosol Deposition in the Developing Human Lung

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ACID AEROSOL DEPOSITION IN THE DEVELOPING HUMAN LUNG

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T.B. MARTONEN

Health Effects Research Laboratory, U.S. Environmental
Protection Agency, Research Triangle Park, NC 27711.

ABSTRACT

Computations of aerosol deposition as affected by (i) aerosol hygroscopicity, and (ii) human age, have been done using a validated theoretical model. The behavior of inhaled H_2SO_4 particles subsequent to water vapor uptake significantly influences their relative spatial distribution patterns within human lungs. These observations must be accounted for in risk assessment protocols since compartments of the lung have distinctive clearance processes and reactions to toxic materials. Calculations also establish that subject age is a critical variable to incorporate into health effects studies. This is of particular importance since children are a potentially sensitive subpopulation of concern related to inhalation exposures to airborne contaminants.

KEYWORDS

acid aerosols, developing lung, particle deposition, health effects

INTRODUCTION

The combustion of high sulfur content fossil fuels produces irritant and toxic airborne particles of health effects concerns. To accurately assess potential hazards, the quantity of inhaled particulate matter that is actually deposited within the lung must be ascertained. Indeed, since the different morphological compartments have distinctive clearance processes and biological reactions, it is most important to know the spatial distribution of the total dose delivered to the lung.

It is necessary to consider all ages of the population in risk assessment protocols related to ambient atmospheres, especially since children have been identified as a potentially sensitive subgroup. For adult subjects, the deposition sites of inhaled particles can be determined via inhalation exposure experiments. However, for children the matter is not so straightforward due to related legal testing constraints.

regional dispersion of inhaled pollutant sulfate particles will be quantitated. Specifically, a validated mathematical deposition model is used to study the tracheobronchial and pulmonary patterns of H_2SO_4 droplets relative to nonhygroscopic, laboratory Fe_2O_3 particles. The model is then applied to the prediction of inhaled particle deposition in the developing human lung.

METHODS

The lung may be divided into two main compartments: (i) the tracheobronchial (TB) tree, and (ii) the pulmonary (P) region. The TB tree is composed of smooth-muscle lined, conducting airways. They are ciliated and have a superficial mucus layer. The P airways are the gas exchange area of the lung, and consist of respiratory bronchioles, alveolar ducts and sacs. From the perspective of this text, the key distinction between the TB and P airways will regard their respective clearance mechanisms.

Lung Clearance Processes

The compartments of the lung have clearance mechanisms that differ in mode of operation, effectiveness, and rate of particle removal. The TB tree is cleared of deposited particles by the mucociliary system, whereas the P region is swept by macrophage action (and collected particles subsequently delivered to the more proximal TB passages for final dismissal via the mucus elevator). By convention, particles deposited in the TB tree are assumed to be cleared in about 24 hours. Removal from the P region requires an extended time period on the order of days, weeks, perhaps months. These determinations of the so called "fast" and "slow" phases of clearance are based upon clinical observations which are somewhat subjective. This is explained below.

The patterns of aerosols within the lung are not directly measured. Rather, a determination of the spatial distributions of particles among airways are based upon clearance measurements, or more precisely, of retention as a function of time. The scenario is this: radiolabeled particles are inhaled by test subjects, and gamma camera images taken at defined time intervals. To past investigators, experience has taught that the difference between initial activity (i.e., detected immediately at the conclusion of deposition exposures) and that at approximately 24 hours signifies the quantity originally deposited in, and for insoluble particles, subsequently removed from, the TB tree. The activity remaining in the lung after one day thus represents particles originally deposited in the P compartment, and not yet removed from the lung.

Analyses of data from systematic series of particle deposition experiments with human subjects, however, have indicated ambiguities, suggesting the presence of a delayed component of TB clearance, or alternatively an advanced component of P clearance (Chan and Lippmann, 1980; Stahlhofen *et al.*, 1980). Regarding this issue, Smaldone *et al.* (1988, p. 19) have concluded that "...activity remaining in the lung at 24 hrs reflects much more than deposition in terminal airways and alveoli, especially in patients with lung disease." Their interpretation of published inhalation exposure data is that a significant amount of particle activity in the lung after one day resides on ciliated airways.

The primary particle deposition mechanisms in the human lung are inertial impaction, sedimentation and diffusion. To describe the deposition efficiencies of the respective mechanisms, I shall employ the system of equations proposed by Martonen (1980) which are written in terms of particle parameters, lung dimensions, and breathing conditions.

Particles which are hygroscopic will absorb water vapor present in the warm, humid atmosphere of the lung. Therefore, particles will change in size, shape and density while traveling through TB and P airways, while being acted upon by deposition forces. Temperature (T) and relative humidity (RH) environments for the human lung have been presented by Martonen *et al.* (1989b). To describe particle dimensions for prescribed T and RH values, I shall use the laboratory findings of Tang and Munkelwitz (1977). Densities may be computed using Eq. (15) of Martonen (1980).

The Maturing Human Lung

Technical descriptions for the morphologies of the developing human lung have been derived by Martonen *et al.* (1989a). The composition of the TB and P compartments, together with related dimensions (lengths, diameters) and orientations (angles) of the respective individual airways, were described by mathematical expressions as functions of subject age. The formulas were based upon published clinical studies and anatomical measurements, and will be used in this work.

Table 1. Age-dependent respiratory parameters as a function of subject physical activity levels. Breathing frequency and tidal volume are listed as f and TV.

Subject Age (months)	Resting		Moderate		Exertion	
	f (min ⁻¹)	TV (ml)	f (min ⁻¹)	TV (ml)	f (min ⁻¹)	TV (ml)
7	35	42	32.0	187	70	165
22	28	84	36.9	222	70	328
47	22	152	37.3	289	68	570
98	18	266	28.4	494	60	1190
240	14	500	15.5	1291	40	3050

The breathing conditions which define certain levels of physical activity for different subject ages are compiled in Table 1. The values are used to select appropriate airstream velocity profiles in TB and P airways for related computations of particle deposition probabilities.

RESULTS

For brevity, I shall focus on resting conditions, or the sedentary levels descriptive of everyday occurrences.

functions of subject age. The deposition patterns of hygroscopic H_2SO_4 and control Fe_2O_3 aerosols are depicted. To examine particles in the developing lung, let us consider the control aerosols. For a given size, deposition increases monotonically with age; for example, a $3.2 \mu\text{m}$ particle has deposition values ranging from ≈ 0.35 (7 months) to ≈ 0.25 (adult). For any selected age, the effect of hygroscopicity within the warm, humid airways has a very pronounced effect upon particle deposition efficiencies. Considering the aforementioned ages, aerosol hygroscopicity increases deposition to ≈ 0.77 (7 months) and ≈ 0.65 (adult). The relative increases directly attributable to water vapor uptake, therefore, are factors of 1.2 and 1.6, respectively. The same monotonic relationship between age and deposition as observed with Fe_2O_3 particles is found with H_2SO_4 .

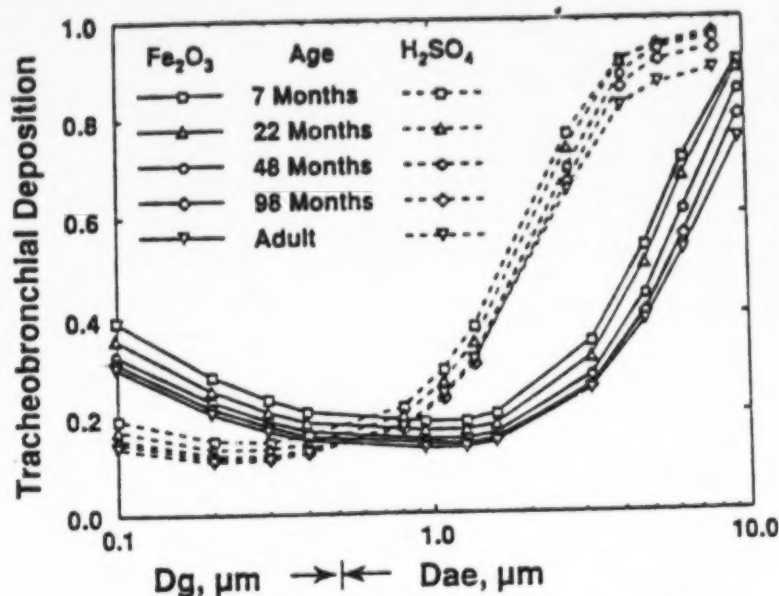


Figure 1. Tracheobronchial distribution of H_2SO_4 particles in the developing human lung.

Interestingly, there is a switch-over in the overall effect of hygroscopicity upon TB and P deposition, which occurs within the $0.4 - 0.8 \mu\text{m}$ particle size interval. For larger sizes, particle growth results in an increase of deposition due to improved efficiencies of the inertial impaction and sedimentation mechanisms. For smaller sizes, hygroscopicity has a lessening influence related to reduced effectiveness of the diffusion mechanism.

In Figure 2, the distribution of particulate matter in the alveolated compartment of the lung is demonstrated. The effect of age is more complicated than in the TB airways; i.e., it's not a monotonic function. However, the adult and 48 month-old cases form upper and lower bounding curves for most test conditions. Regarding hygroscopicity, the most obvious effects are to shift the deposition curve maxima to smaller particle sizes. The Fe_2O_3 aerosols peak within the $3-5 \mu\text{m}$ size range, whereas for the H_2SO_4 the highest deposition values are observed within the $1 - 1.5 \mu\text{m}$ interval. The magnitude of deposition is not too affected; for control aerosols the maximum is ≈ 0.34 , the value is ≈ 0.40 for the pollutants.

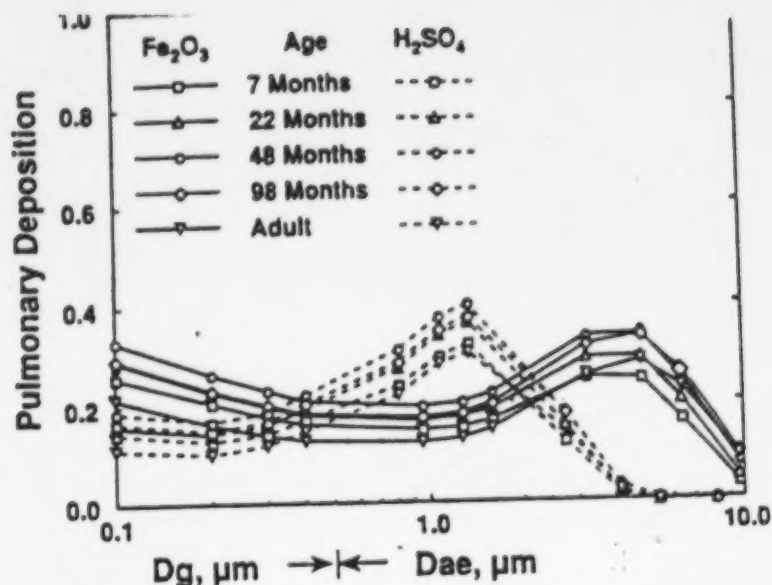


Figure 2. Pulmonary distribution of H₂SO₄ particles in the developing human lung.

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